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United States
Department
of Agriculture

Forest Service

**Intermountain
Research Station**

Research Note
INT-412

March 1993

Trials of Mixed-Conifer Plantings for Increasing Diversity in the Lodgepole Pine Type

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Abstract—Greater forest diversity is needed in the lodgepole pine forest cover type—particularly, along and east of the Continental Divide in Montana—if large-scale losses from cyclical bark beetle outbreaks and subsequent wildfires are to be reduced. Three species were compared to lodgepole pine in a test of mixed-species planting in three ecological habitat types of the lodgepole pine type. Differences in seedling survival, condition, and growth were observed among species and among habitat types by the fifth year after planting. The results indicate Engelmann spruce and Douglas-fir can be used to attain mixed-species stands by interplanting naturally regenerated lodgepole pine seedling stands. Western larch probably can succeed only when planted in moist Douglas-fir, spruce, or the warmer subalpine fir habitat types east of the Continental Divide. Because of greater frost tolerance, western larch x alpine larch hybrids are promising for increasing forest diversity in some of the colder subalpine fir habitat types.

Keywords: *Pinus contorta,* forest cover diversity, forest management, silviculture, forest cover type

The mountain variety of lodgepole pine (*Pinus contorta* var. *latifolia*) characterizes forest cover on more than 12 million acres of commercial forest lands of the Western United States (Barger and Fiedler 1982). About 4.8 million acres of these forests occur in Montana (Fiedler 1987), where debate on their management has been quite spirited. About 35 percent of the commercial lodgepole pine cover type (Pfister and McDonald 1980) in Montana has been placed into reserved or deferred land-use status in National Forest management plans. Timber harvest is precluded until issues such as those presented by roadless areas, critical watersheds, critical wildlife habitats, recreation areas, and sensitive esthetic concerns are resolved. Yet, timely sawtimber harvest and culture of immature stands is of critical importance if a more diverse distribution of age classes and species is to reduce large-scale losses from cyclical bark beetle outbreaks and subsequent wildfires (Cole 1985, 1989; Coston 1985).

Age-class diversity can be enhanced in the lodgepole pine type by early stand replacement; that is, by clearing and regenerating stands or portions of stands before they attain sawtimber size (Cole 1989). The most likely candidates for this practice are the more seriously overstocked poletimber stands (5.0 to 8.9 inches diameter at breast height [d.b.h.]) that can be used for roundwood products and firewood. About 1.6 million acres of poletimber stands are outside reserved lands in Montana (derived from Fiedler 1987). Age-class diversity can also be enhanced by replacing stagnated sapling stands (<5.0 inches d.b.h.), many of which will never grow big enough to produce merchantable products and are of low health and vigor. Although management has steadily reduced the total acreage of stagnated lodgepole pine in commercial forest lands over the past 30 years, most National Forests in western Montana still have areas where lodgepole pine is stagnated. Age-class mosaics in lodgepole pine forests can be readily visualized and mapped with geographical information systems. The chosen mosaic can be attained by identifying the size and location of cutting units and clearing and preparing the chosen sites for natural regeneration in the scheduled years. The resultant stands will predominantly be pure, even-aged lodgepole pine.

Species diversity is harder to attain, especially when lodgepole pine stands are naturally regenerated. Lodgepole pine is very aggressive at pioneering cleared sites, while most of its associates, with the exception of western larch (*Larix occidentalis*), are shade-tolerant species that take years to become established. Some of the reasons these species aren't

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as likely to become established include: elimination of seed sources by large-scale, stand-replacing fires, greater sensitivity of flowering structures to growing season frosts, less tolerance of high water tables, and greater seedling mortality from low temperatures, drought, or other climatic extremes that are intensified by clearing (Volland 1985). The factors influencing seed supply, germination, and first-year survival are probably the most critical. This suggests that planting might produce mixed-species stands in habitats where species associated with lodgepole pine do not naturally regenerate, or do so very slowly. This study examines that possibility.

Three western Montana habitat types in which lodgepole pine expresses a dominant seral or persistent successional role (Pfister and Daubenmire 1975) were selected for mixed-species plantings. The plantings were part of a number of silvicultural prescriptions evaluated in the STEM Program, a study of management options for small-stem stands of lodgepole pine (Barger 1987). Species available for planting were lodgepole pine, western larch, Engelmann spruce (*Picea engelmannii*), and the Rocky Mountain variety of Douglas-fir (*Pseudotsuga menziesii* var. *glauca*). This paper reports differences in survival and growth among the species for the first 5 years after planting and discusses habitat-type and species differences that affect opportunities for increasing forest diversity.

SITE DESCRIPTIONS AND STUDY PROCEDURES

Three small clearings, from 1.0 to 1.9 acres, were established by clearcutting during 1983 and 1984 in different habitat types in the Deerlodge (DNF), Gallatin (GNF), and Lewis and Clark (LNF) National Forests in western Montana. All stem wood greater than 3 inches in diameter was removed from the areas. Smaller stems and tops were lopped and scattered across the clearcuts. The clearings were broadcast burned after the fuels dried for 12 to 18 months. About one-third of each clearing was reserved for natural regeneration, one-third for mixed-species planting, and one-third for planting only lodgepole pine. The lodgepole plantation allowed a long-term comparison of planting with natural regeneration, in case survival in the mixed-species plantings turned out to be insufficient for such a comparison. Natural regeneration is being monitored on milacre (one-thousandth of an acre) plots established to sample 5 percent of the areas reserved for natural regeneration. Plot centers were marked with plastic stakes and tagged to enable plots to be relocated when meaningful comparisons of natural regeneration development can be made.

Seed for the western larch seedlings came from an elevation of 5,000 ft on the Seeley Lake Ranger District, Lolo National Forest. The spruce planted at the DNF site also originated from the Seeley Lake Ranger District, but at an elevation of 5,600 ft. The Douglas-fir and lodgepole pine planted at the DNF site originated at elevations of 5,900 and 6,000 ft, respectively, on the Helena Ranger District, Helena National Forest. Seed for the spruce, Douglas-fir, and lodgepole pine planted at the GNF and LNF sites came from the Bozeman Ranger District, Gallatin National Forest—at elevations of 6,800 ft for the spruce and Douglas-fir and 7,000 ft for the lodgepole pine.

Deerlodge National Forest

This site is located at approximately 46°30' N. lat. and 113°30' W. long. in the upper Willow Creek drainage of the Philipsburg Ranger District about 26 miles northwest of Philipsburg, MT. The site is identified as Corduroy Creek East in the STEM Program studies mentioned above. The site is classified in the *Abies lasiocarpa/Vaccinium caespitosum* habitat type (ABLA/VACA h.t.) (Pfister and others 1977). Site data are summarized in table 1. Temperature data were obtained from Soil Conservation Service records for Philipsburg and adjusted to the specific location with MTCLIM, a mountain microclimate simulation model (Hungerford and others 1989). Precipitation was read from a Soil Conservation Service precipitation map. Conditions for lodgepole pine regeneration are very favorable, although temperatures will fall below 26 °F in both May and June about 2 years out of 10—such temperatures retard seedlings that are not acclimated to them. The cleared area is 1.9 acres. It is bounded on the north by an 85-year-old lodgepole pine stand of 1.9 acres, thinned to 155 ft^2 of basal area per acre in 1983. The clearing is bounded on the east, south, and west by the unthinned parent stand that averages about 212 ft^2 of basal area per acre. Soils are frost churned, noncalcareous, sandy to loamy skeletal in texture, and are typically underlain with bedrock at depths of 4 to 8 ft. Water-holding capacity is low to moderate, indicating that water may limit plant growth in late summer.

Lewis and Clark National Forest

This site is located at approximately 46°46' N. lat. and 110°50' W. long., about 5 miles southwest of Neihart, MT. The site is identified as the Wet Park site of the STEM Program. The site is classified as the *Vaccinium caespitosum* phase of the *Abies lasiocarpa/Calamagrostis canadensis* habitat type (ABLA/CACA-VACA h.t.). Descriptive site data are summarized in table 1. Temperature data were obtained from Soil Conservation Service records for Neihart and adjusted to the higher elevation of the study site with procedures of the MTCLIM microclimate simulation model

Table 1—Descriptive site data

Site	Habitat type	Elevation	Aspect	Slope	Annual precipitation	Average July temperature	
						Minimum	Maximum
		Feet		*Percent*	*Inches*	°F	
Deerlodge National Forest	ABLA/VACA[1]	5,900	SW	<4	22	39	76
Gallatin National Forest	ABLA/VASC-VASC[2]	6,800	N	<2	38	40	80
Lewis and Clark National Forest	ABLA/CACA-VACA[3]	6,800	S	<2	30	41	75

[1]*Abies lasiocarpa/Vaccinium caespitosum* h.t.
[2]*Abies lasiocarpa/Vaccinium scoparium/Vaccinium scoparium* h.t.
[3]*Abies lasiocarpa/Calamagrostis canadensis/Vaccinium caespitosum* h.t.

(Hungerford and others 1989). Site precipitation was estimated from Soil Conservation Service maps. Temperatures fall below 26 °F in both May and June about 2 years out of 10, posing some threat to new growth of seedlings that are not acclimated to such temperatures. The cleared area is 1.0 acres. It is bounded on the north by a 99-year-old lodgepole pine stand, thinned in 1983 to a basal area of about 70 ft^2 per acre. It is bounded on the east, south, and west by the unthinned parent stand that averages about 213 ft^2 of basal area per acre. Soils are undifferentiated alluvial glacial deposits of unknown origin, overlaying quartzite. The soil is a clayey loam to depths of about 12 inches, grading to clay at depths of 12 to 20 inches. These soils are poorly drained and a perched water table is usual, with the consequence that root systems of trees are somewhat restricted. Despite these conditions, lodgepole pine regeneration is generally very prolific.

Gallatin National Forest

This site is located at 44°37' N. lat. and 111°7' W. long., 2 miles south of West Yellowstone, MT. The site is identified as the South Flat study area of the STEM Program. The site is classified as the *Vaccinium scoparium* phase of the *Abies lasiocarpa/Vaccinium scoparium* habitat type (ABLA/VASC-VASC h.t.). Site data are summarized in table 1. Climatic data for the site were obtained from Soil Conservation Service records for the West Yellowstone and Whiskey Creek weather stations, both within 3 miles of the plantation site. The frost-free season at this site is typically only 50 to 90 days with temperatures falling below 26 °F in May, June, and July about 2 years out of 10. Such temperatures can damage seedlings that are not acclimated to them. The cleared area is 1.3 acres. It is bounded on the north by a 96-year-old lodgepole pine stand, thinned in 1983 to approximately 130 ft^2 of basal area per acre. It is bounded on the east, south, and west by the unthinned parent stand that averages about 160 ft^2 per acre of live basal area. Soils are siliceous glacial outwash and alluvial deposits derived from obsidian and rhyolite. A thin loess cap about an inch thick grades to a coarse sandy loam, which in turn grades to a gravelly sandy loam at a depth of about 4 inches. The gravelly profile extends to bedrock at depths beyond 5 to 6 ft. These soils do not hold water well below 4 to 6 inches; hence, soil moisture is commonly limiting for plant growth in late summer. Despite these conditions, lodgepole pine readily regenerates.

Planting Procedures

Seedlings were planted at 10-ft intervals in rows spaced 10 ft apart. Two seedlings were planted 12 inches apart at each spot to provide a greater sample size to evaluate survival. In the mixed-species plantings, four species were planted alternately in each row: lodgepole pine, western larch, Douglas-fir, and Engelmann spruce. All seedlings planted were 2-0 bareroot stock (2 years old in the nursery, with no years planted outside), grown at the U.S. Forest Service's Northern Region Nursery, Coeur d'Alene, ID. After lifting from the nursery, seedlings were placed in cold storage until the week of planting, then kept in picnic coolers with ice until planted. Seedlings were planted with a planting bar that had a blade 12 inches long and 5 inches wide. A 2- by 2-ft area was scalped to mineral soil just before planting to discourage competition from grasses. To limit competition between seedlings when both survived, the smaller seedling was removed

after the fifth year; however, the percent survival and average height reported here are based on all seedlings planted.

Measurements and Analysis

Survival and heights of seedlings were recorded in 1987, 1988, 1989, and 1991, although not for all sites in all years. Measurements were skipped in 1987 at the DNF site, in 1989 at the GNF site, and in 1990 at all three study sites. Fifth-year measurements were taken at all sites in 1991. Condition of seedlings was evaluated by recording the vigor of each surviving seedling and whether its top had been lost. Percent survival and average height were calculated for each species for each year of measurement. Average annual height growth was calculated for each species and site for the 3-year period 1988 to 1991. The percentages of seedlings that were healthy, in poor vigor, or damaged were calculated in 1991 for each species and site. Because plantings were not replicated within habitat types, statistical tests of habitat types and species differences were not performed. Instead, tables and graphs were used to examine relative differences between species within habitat types and between habitat types for a given species.

RESULTS

The survival and condition of planted seedlings varied, depending on the species and the habitat type (table 2). Survival differences between species also changed from the second year after planting (1988) to the fifth year after planting (1991) in all three habitat types. Although formal statistical tests could not be made, species differences in survival within and between habitat types are strongly suggested in figure 1.

Overall, spruce and lodgepole pine had the highest survival rates with lodgepole showing the least change in survival from year to year. Spruce had the highest survival rate in the ABLA/VACA h.t. (DNF) and ABLA/CACA-VACA h.t. (LNF), but the initially high survival in the ABLA/VASC-VASC h.t. (GNF) declined so much that its survival was less than Douglas-fir by the fifth year. By 1991 western larch survival was low in all three habitat types, although it had been relatively high in the first 2 years in the ABLA/CACA-VACA h.t. (LNF). Although initial survival was generally lower in the ABLA/VACA h.t. (DNF), survival declined the least during succeeding years in this habitat type. Apparently some factor detrimental to seedling survival of all four species operated here in the first year or two following planting but not in the last 3 years.

Seedlings of species most likely to survive until 1991 were also generally the healthiest, except in the ABLA/VACA h.t. (DNF) plantation where almost all surviving seedlings were rated as healthy, regardless of species (table 2). In contrast, none of the spruce, only about one-fourth of the Douglas-fir, and about half of the western larch were rated healthy in the ABLA/VASC-VASC h.t. (GNF); these species are expected to experience continuing mortality there. In

Table 2—Survival and condition of four species planted in mixed-species stands in different habitat types in 1986

Habitat type National Forest	Species[1]	Surviving 1987	Surviving 1988	Surviving 1989	Surviving 1991	1991 condition: Poor vigor	1991 condition: Lost top	1991 condition: Healthy
		Percent						
ABLA/VACA[2]	SP	—	80	68	63	0	5	95
Deerlodge	LP	—	58	57	54	0	4	96
National Forest	DF	—	18	16	11	0	0	100
	WL	—	24	12	12	0	0	100
ABLA/VASC-VASC[3]	SP	87	74	—	29	98	4	0
	LP	99	96	—	93	0	15	85
Gallatin	DF	79	56	—	37	61	15	24
National Forest	WL	56	40	—	17	39	14	47
ABLA/CACA-VACA[4]	SP	98	94	75	56	15	15	70
	LP	73	64	54	52	4	11	85
Lewis and Clark	DF	40	12	2	0	—	—	—
National Forest	WL	72	64	12	2	0	100	0

[1]SP = Engelmann spruce; LP = lodgepole pine; DF = Douglas-fir; WL = western larch.
[2]*Abies lasiocarpa/Vaccinium caespitosum* h.t.
[3]*Abies lasiocarpa/Vaccinium scoparium/Vaccinium scoparium* h.t.
[4]*Abies lasiocarpa/Calamagrostis canadensis/Vaccinium caespitosum* h.t.

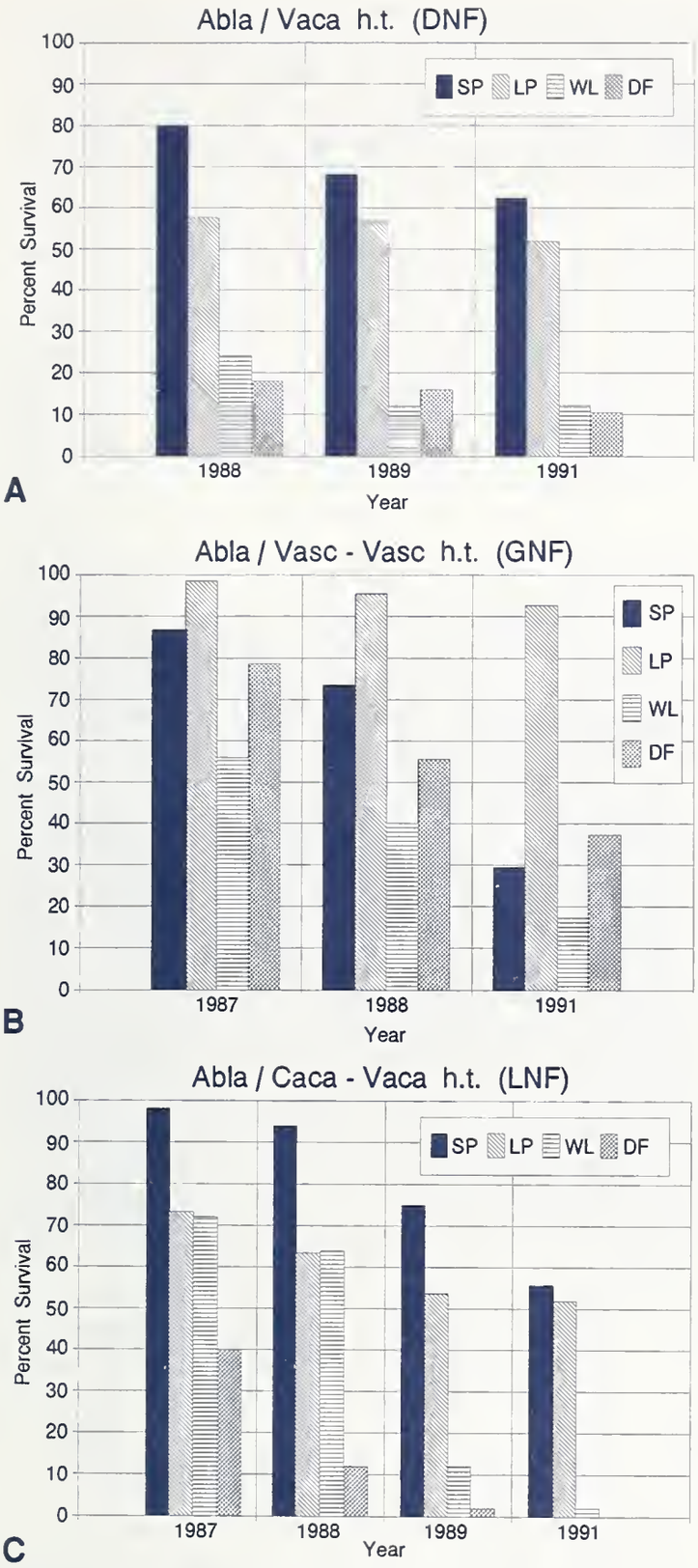

Figure 1—Annual percent survival for the first 5 years following planting of Engelmann spruce (SP), western larch (WL), Douglas-fir (DF), and lodgepole pine (LP) 2-0 bareroot seedlings in the (A) *Abies lasiocarpa/Vaccinium caespitosum* h.t., (B) *Abies lasiocarpa/Vaccinium scoparium/Vaccinium scoparium* h.t., and (C) *Abies lasiocarpa/Calamagrostis canadensis/ Vaccinium caespitosum* h.t.

addition to growing-season frosts, excessively drained soils may also be a detriment to western larch, Engelmann spruce, and Douglas-fir seedlings. Only lodgepole pine appears to have good prospects there. None of the lodgepole pine had poor vigor, however, and the 15 percent missing tops lost them almost exclusively to browsing ungulates. Likewise, 11 percent of the lodgepole pine planted in the ABLA/CACA-VACA h.t. (LNF) lost tops to browsing. Damage to terminal leaders of spruce, Douglas-fir, and western larch seedlings in the ABLA/VASC-VASC h.t. (GNF) and ABLA/CACA-VACA h.t. (LNF), appeared to be primarily due to freezing injury, which may also be implicated in the poor vigor in 1991 of Engelmann spruce and Douglas-fir in these habitat types. The planting sites representing both of these habitat types have a 20 percent probability of temperatures falling below 26 °F in May, June, and July. It appears that every few years freezing temperatures sometime during the growing season damage seedlings less hardy than those of lodgepole pine. The perched water table of the Wet Park site also might have contributed to the loss of Douglas-fir and western larch in the ABLA/CACA-VACA h.t. (LNF).

Total heights of planted seedlings varied noticeably between species in the first 5 years following planting in each habitat type—and for some species, varied considerably between habitat types (fig. 2). Height differences between species generally corresponded with their health in both the ABLA/VASC-VASC h.t. (GNF) and ABLA/CACA-VACA h.t. (LNF) plantations. In the ABLA/VACA h.t. (DNF) plantation all species were similarly healthy in 1991 (table 3). However, the seedlings of different species were not the same height when planted. Therefore, the total height is not a good comparison for species growth since planting. In its place, average annual growth percent was computed for the period 1988 to 1991. Species were compared within and across habitat types (table 4). Lodgepole pine had the highest average annual growth percent in each of the three habitat types—averaging 35.5 percent across all habitat types. Spruce had the next highest average annual growth percent across all habitat types, 22.6 percent, followed by Douglas-fir, 14.8 percent, and western larch, 5.4 percent. Spruce growth exceeded Douglas-fir in the ABLA/VACA h.t. (DNF) and ABLA/CACA-VACA h.t. (LNF), but not in the ABLA/VASC-VASC h.t. (GNF). There Douglas-fir had an average annual growth percent 2.4 points higher. Douglas-fir was a total failure in the ABLA/CACA-VACA h.t. (LNF) where all seedlings had died by 1991. Similarly, only one unhealthy western larch seedling remained alive in the ABLA/CACA-VACA h.t. (LNF) in 1991. Western larch seedlings grew an average of only 5 percent in each of the last 3 years in

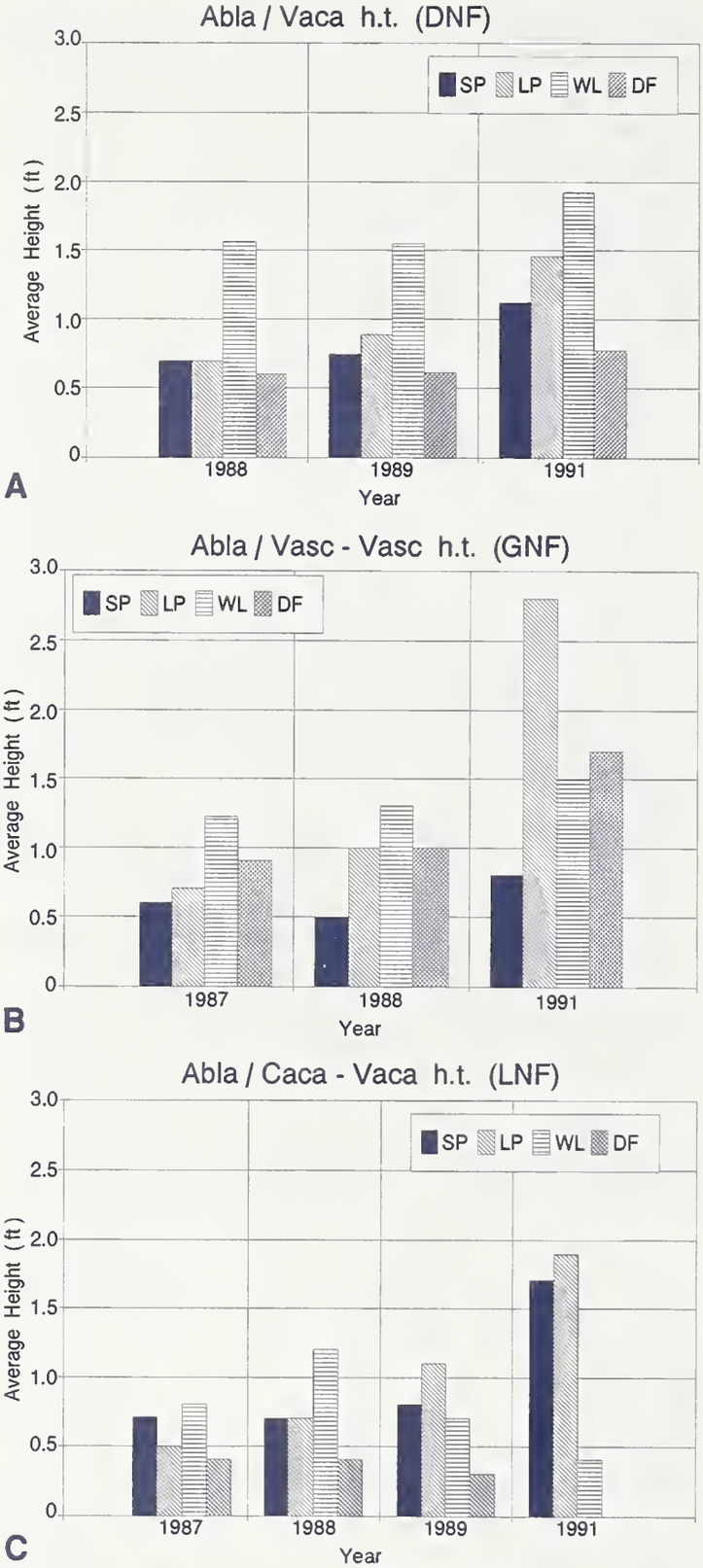

Figure 2—Average height of Engelmann spruce (SP), western larch (WL), Douglas-fir (DF), and lodgepole pine (LP) 2-0 bare-root seedlings planted in 1986, for the years 1987 to 1991 in the (A) *Abies lasiocarpa/Vaccinium caespitosum* h.t., (B) *Abies lasiocarpa/Vaccinium scoparium/Vaccinium scoparium* h.t., and (C) *Abies lasiocarpa/Calamagrostis canadensis/Vaccinium caespitosum* h.t.

the two habitat types where it persisted—markedly less than the other species. Table 4 shows how the attained heights of table 3 are misleading when comparing species performance, particularly for western larch. In table 3 western larch appears to have done well at two of the study locations—trailing only lodgepole pine. However, table 4 shows western larch to have the poorest average annual growth percent in recent years. Examination of table 3 shows that western larch had relatively high attained heights in early years, but grew little thereafter. Differences in height, height growth, and survival between our plantations cannot be tested statistically. Thus, these results cannot be considered to be representative of the respective habitat types.

DISCUSSION

Extensive experience in the National Forests of western Montana has demonstrated that all four species tested in this study can be successfully established by planting in suitable habitats. The three sites selected for this study provided a rather severe test for most of the species planted. The ABLA/VACA h.t. (DNF) and the ABLA/CACA-VACA h.t. (LNF) were inhospitable to Douglas-fir; the ABLA/VASC-VASC h.t. (GNF) was inhospitable to Engelmann spruce; all three were inhospitable to western larch. Only lodgepole pine survived and grew adequately in all three habitat types. On the basis of these early results, only Engelmann spruce and—to a lesser degree Douglas-fir—appear likely candidates for increasing species diversity in these habitat types. Western larch would be a desirable candidate because it is not greatly susceptible to insects and disease and it has several growth characteristics that are compatible with mixed species management—especially when managed with lodgepole pine (Schmidt and others 1976).

Western larch can grow east of the Continental Divide. It has long been planted in towns there. The author has also observed forest plantings of western larch in the Gallatin Range south of Bozeman, MT; in the Greenhorn Range south of Alder, MT; in the Pioneer Range south of Wise River, MT; in the Bearpaw Mountains south of Havre, MT; and in the Hudson Bay Divide area north of Browning, MT.

In northern Idaho and western Montana western larch has performed best in mixed-species management on sites characterized by queencup beadlily (*Clintonia uniflora*). However, even if larch performed moderately in other habitat types, it could enhance forest diversity in stands dominated by lodgepole pine because circumstances limit natural regeneration of larch. In Montana increased forest diversity is especially needed along and east of the Continental Divide, which essentially defines the eastern boundary of western larch's natural

Table 3—Average height and condition summary of four species planted in stands in different habitat types in 1986

Habitat type National Forest	Species[1]	Seedling height 1987	1988	1989	1991	1991 condition Poor vigor	Lost top	Healthy
		Feet				Percent		
ABLA/VACA[2]	SP	—	0.7	0.7	1.1	0	5	95
Deerlodge	LP	—	.7	.9	1.4	0	4	96
National Forest	DF	—	.6	.6	.8	0	0	100
	WL	—	1.6	1.5	1.9	0	0	100
ABLA/VASC-	SP	0.6	.5	—	.8	98	4	0
VASC[3]	LP	.7	1.0	—	2.8	0	15	85
Gallatin	DF	.9	1.0	—	1.7	61	15	24
National Forest	WL	1.2	1.3	—	1.5	39	14	47
ABLA/CACA-	SP	.7	.7	.8	1.7	15	15	70
VACA[4]	LP	.5	.7	1.1	1.9	4	11	85
Lewis and Clark	DF	.4	.4	.3	—	—	—	—
National Forest	WL	.8	1.2	.7	—	0	100	0

[1]SP = Engelmann spruce; LP = lodgepole pine; DF = Douglas-fir; WL = western larch.
[2]*Abies lasiocarpa/Vaccinium caespitosum* h.t.
[3]*Abies lasiocarpa/Vaccinium scoparium/Vaccinium scoparium* h.t.
[4]*Abies lasiocarpa/Calamagrostis canadensis/Vaccinium caespitosum* h.t.

occurrence. Here, large areas are dominated by lodgepole pine and Douglas-fir forest types on habitat types of the subalpine fir and Douglas-fir climax series (Pfister and others 1977). These areas could be made more heterogeneous by spatially varying the size and location of regeneration harvest units and by varying the species composition, form, and rotation ages of regenerated stands. Therefore, western larch would add significantly to managers' options, wherever it could be added to the mix of tree species.

Because it is increasingly evident that the effects of frost on flowering and seed production often limit western larch reproduction (Shearer 1990), it is interesting to consider habitats where it might grow adequately even though it cannot reproduce naturally. I reviewed the constancy (frequency of occurrence) and canopy coverage tables underlying the forest habitat type classification for Montana (Pfister and others 1977). A number of habitat types found east of the Continental Divide in the *Pseudotsuga*, *Picea*, and *Abies lasiocarpa* series have understory plant associations similar to western larch sites. Because of infrequent growing season frosts, these habitat types are likely to be more amenable to western larch. The most promising are those in the *Picea* and *Pseudotsuga* series that have adequate moisture for western larch.

Table 4—Average annual height growth percent (AAGP) for the period 1988 to 1991, by habitat type and species

Species	ABLA/VACA[1]	ABLA/VASC-VASC[2]	ABLA/CACA-VACA[3]	Species AAGP
	Percent			
Engelmann spruce	16.3	17.0	34.5	22.6
Lodgepole pine	26.0	41.0	39.5	35.5
Douglas-fir	10.1	19.4	—	[4]14.8
Western larch	5.9	4.9	—	[4]5.4
Average annual height growth	14.6	20.6	[5]37.0	

[1]*Abies lasiocarpa/Vaccinium caespitosum* h.t.
[2]*Abies lasiocarpa/Vaccinium scoparium/Vaccinium scoparium* h.t.
[3]*Abies lasiocarpa/Calamagrostis canadensis/Vaccinium caespitosum* h.t.
[4]Average based on only two habitat types, due to failure of species in ABLA/CACA-VACA h.t. plantation.
[5]Average based on only two species, due to failure of Douglas-fir and western larch to survive in this habitat type.

Mixed-species stands that include larch might succeed in some subalpine fir habitat types if frost damage could be lessened. Perhaps larch could be interplanted in properly spaced stands of lodgepole pine, or lodgepole pine and spruce—after the stands have grown enough to ameliorate the radiation extremes of the clearcut but before the stands have closed too much. A solution with much wider application would be to increase the frost resistance of western larch. Frost-hardy western larch x alpine larch (*Larix lyallii*) hybrids could be planted in sufficiently moist frost-prone habitat types of the subalpine fir series to test this approach. Intermountain Research Station studies are under way to determine the environmental parameters of habitats in which subalpine larch x western larch container-grown seedlings grow well. Early results indicate the hybrids' frost hardiness is intermediate between the parents (C. Carlson 1992).

In summary, this study confirms that forest diversity can be increased by planting Engelmann spruce and Douglas-fir in many habitat types of the subalpine fir series where lodgepole pine usually dominates following clearcutting. This could be accomplished by controlling the stocking of naturally regenerated lodgepole pine seedling stands and interplanting with spruce, or Douglas-fir, or both. This study indicates such opportunities with western larch are limited, unless frost-resistant planting stock becomes available. Alpine larch x western larch hybrids offer promise in this regard and are being studied for this purpose, among others. In warmer and sufficiently moist subalpine fir, Douglas-fir, and spruce habitat types along and east of the Continental Divide, mixed-species plantings that include western larch still seem to merit study as one means of enhancing forest diversity.

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☆U.S. GOVERNMENT PRINTING OFFICE: 1993-774-041/61035

Printed on recycled paper

Intermountain Research Station
324 25th Street
Ogden, UT 84401

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